Modern Methods of Prospecting for Limestone at Cemento Polpaico

Searching for limestone deposits in the coastal Cordilleras of Central Chile with satellite photos.

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1. GENERAL

There are very few limestone deposits in Chile. This applies particularly to the central region of this extremely long country of 4000 km. Only in the south (Madre de Dios archipelago) and in the cordilleras of the Andes at an altitude of 3000 to 5000 m above sea-level near the border to Argentina, are there any significant limestone deposits.

The two factories which satisfy the needs of the greater part of the market round Santiago and the rest of the country utilize deposits which incur heavy raw-material costs. Cemento Polpaico utilizes a deposit of siliceous limestone 40 km north of Santiago, a material which requires a special flotation treatment, while Cemento Mélon exploits a lime-stone deposit of good quality situated some 120 km north of Santiago, where it is mined 500 m below ground-level.

In view of this situation, it was decided in 1992 that prospecting for new limestone deposits should be carried out along the coastal Cordilleras, roughly between 31 and 33° of longitude S, representing an area of some 12 000 km^2. One third of this area exhibited geological formations in which limestone could be expected with a certain degree of probability.

The exploration of such a large area demanded many days of field work on the spot. To reduce this to a minimum, the most interesting zones had to be selected beforehand, and then work concentrated on them. The most obvious question was: Where are these areas and how can they be selected? To obtain an answer it was decided to resort to the analysis of satellite photos.

This procedure is used quite often when prospecting for metallic raw material, especially in Northern Chile, and astonishing results have been achieved. One company, for instance, located a large gold deposit in the region of Zapaleri (high cordilleras of the Atacama region) solely with the aid of satellite photos, and this long before the geologists working for the competitors had returned to their offices, analyzed their data and likewise reached the conclusion that the area was of interest. With non-metallic deposits not so much experience has been acquired, but it is nevertheless very promising, as the discovery of large saltpetre shows deposits in the Atacama Desert. And thereby hangs a tale: When examining the satellite photos, a line was observed which crosses the entire desert and consisted of saltpetre. When this remarkable phenomenon was examined on site, the line was found to be the route by which the Incas used to transport saltpetre to Peru. The saltpetre recorded in the photos was lost on the way by the pack animals.

In view of the excellent results obtained with this method it was decided that it should be used for limestone, despite the lack of experience with this material. First the feasibility of the method was tested with photos of the known deposits in the area surrounding the works of Cemento Polpaico. They are located between 32°30' and 33°30' longitude (Fig. 1). Owing to the proximity of the area and its good accessibility, it was an easy matter to check the results. It ought to be possible to see the limestone deposits of Cemento Polpaico and Mélon, which were of use in analysing the satellite information.

These photos and the software for their analysis cost about US$ 4000 per photo, plus US$ 10 000 for the program. The Centro de Estudios Espaciales of the University of Chile also possesses some photos, as well as suitable equipment and experts, so that it was possible to cooperate directly with this institute at a cost of US$ 500 per day. For the three days occupied by evaluating the photos the total cost worked out at US$ 1500 for an area of 5000 km2. Assuming that a field geologist would have cost US$ 50 per day, it would have been possible to finance 30 field days at this price. But then the geologist would have had to explore 170 km2 per day, which of course is impossible. Thus the method of analysing satellite photos costs decidedly less.

2. THEORETICAL INTRODUCTION

2.1 General

The use of satellite photos of the Earth's surface has grown in importance for geological investigations since the seventies, when the first satellite of the LANDSAT series was put in orbit. With satellites certain information can be acquired quicker and more economically than with conventional methods.

The photo gives a representative impression of the surface, though vegetation can prove disturbing. For this reason the method provides better results in semi-dry, desert-like areas where the rock strata are more exposed.

In the latest method known as remote sensing, a sensor (or a group of sensors) suitable for measuring the intensity in a given waveband in the electromagnetic spectrum is mounted on an aircraft, a helicopter or a satellite, so as to cover the largest possible area for prospecting. There are a number of satellites fitted in this way, such as LANDSAT, SPOT and NOAA, which were developed for the particular purposes.

2.2 LANDSAT satellites

The LANDSAT satellites (MSS and TM) which were put in operation by the NASA, are located in a polar orbit which passes the illuminated area of the Earth several times a day moving west-wards so that within 16 days the whole of the Earth's surface has been covered.

The photos come from two sensors: a Multi-Spectral Scanner (MSS)and a Thematic Mapper (TM). Both of them divide the image into small elements (pixels) and measure their intensity of radiation. The components of the sunlight reflected by the Earth are detected in both the visible and the infrared region. This digital information is transmitted to Earth, where it is processed to products resembling aerial photos, false-colour photos, which are then analysed and evaluated.

The TM sensor is more useful for geology than MSS. It produces images in 7 bands of the electromagnetic spectrum, each covering an area of 185 x 185 km, the resolution (definition of objects) being between 30 and 120 m (thermal infrared). Each band represents a segment of the electromagnetic spectrum, defined as follows.

Band	Micrometer	Spectral range
B 1	0.45-0.52	visible blue
B 2	0.52-0.57	visible green
B 3	0.63-0.69	visible red
B 4	0.76-0.90	near infrared
B 5	1.55-1.75	remote infrared
B 6	10.8-12.5	thermal infrared
B	2.08-2.35	remote thermal infrared (SWIR)

2.3   Generation of images

The data stored on magnetic tape can be processed at any time to obtain the desired products. These result from a combination of three information bands, allocated beforehand to the three traditional colours red, green or blue (R/G/B).

The information bands may contain one of the following: The various bands which are received directly from the satellite, the product of a mathematical operation based on information from various real bands (band sum, band quotient, etc.), or the PC (principal components). Each separately measured band contains a definite component of the other bands depending on the technical features of the sensor. Via statistical treatment of the data of the various bands of an image, algorithms are generated (PCI, which in turn generate new bands with bands independent of one another. When an image is displayed, it can be modified so that the information needed is acquired.

2.4   Analysis of the information

When generating an image, one should have a clear idea of what information is needed and how it should be interpreted. Experience has proved that there are definite bands and combinations that are particularly well suited for use in geology. In order to analyse an image (on the monitor or as a colour printout), one should have a clear idea of what the false colour concept involves. This means that the colour on the picture is not necessarily the colour of the Earth's surface, but:

♦   the colour results from the allocation of a definite band to a colour on the monitor

♦   the colour results from the actual colour of the surface;

♦   the various colours in the picture indicate a difference in the composition of the reflecting surfaces this information is purely of a qualitative nature and does not provide any information on the material, nor the percentage of a definite compound present.

♦   The colour observed results from the reflective properties of the analysed surface, the degree of weathering, the humidity, the structure of the surface etc.

♦   It should also be pointed out that in view of the fact that a satellite photo is based on the reflection of sunlight by the Earth's surface, it depends directly on the time of day, the weather conditions, the season of the year and the angle of observation at the moment the photo is taken.

The simplest method is to compare the false colour pictures of satellite photos with known geological formations in an area. If it proves possible to allocate a colour to a definite kind of stone, it may be assumed that at places where the colour is the same, the lithological conditions will be the same as those in the corresponding reference area.

Although the various bands alone already provide definite information, they can be combined and the properties of the false colours utilized to stress other useful features.

Below, some of the most frequent combinations will be explained (shown in brackets is the colour that appears on the monitor):

B3 (red), B2 (green), B1 (blue): With this combination the various bands are shown with their real colour, a picture being obtained which corresponds to the natural colouring.

B5 (red), B4 (green), B1 (blue): Here a distinction can be made between various rocks and soils in an area with no vegetation. This combination is useful for exploring lithological conditions in volcanic and sedimentary strata.

Other pictures are obtained with the aid of the quotients between the bands. B7/B4 (red), B4/B3 (green), B5/B7 (blue): In this case red demonstrates the presence of iron, green corresponds to vegetation and blue to hydyrophiles and carbonates.

In areas covered with vegetation the ground cannot be seen directly, but employing the following assumption, conclusions can be drawn as to the lithological conditions and the composition of the subsoil. Plants react to the presence of different mineral compounds, the composition of which in turn depends on the lithological conditions. Thus on soil that is rich in calcium carbonate, the plants growing on it may suffer from a disease known as cloriosis (which affects their chlorophyll content). If this anomaly is observed in the plant cover, the area observed may be regarded as of interest in the prospecting for rock containing lime.

The analysis of the PC information (principal components) is rather more complicated because it is obtained with the aid of an algorithm and therefore bears no direct relation to the real conditions on the Earth's surface. This algorithm is specific for each PC and each photo. Its importance can be determined by analysing the formula, the terms of which are different weightings of the various bands. This means that, according to the weighting factor a definite PC is influenced more by definite bands, which then give it is true meaning.

3.   GEOLOGICAL EXAMINATION

3.1   Introduction

The area selected for the examination corresponds to a segment of the coastal Cordilleras situated roughly between 32°30' and 33°30' S in longitude. A photo was used which had been taken by LANDSAT TM at 10 a.m. on a summer morning (March).

In summer this area also exhibits quite an appreciable coverage of vegetation (about 70%), but it decreases notably with increasing altitude. Although this affects the method, it was hoped that interesting places would be found in the uncovered areas as well as limestone outcrops in covered areas. At the strongest resolution of the sensor deposits 30 m or more in size would saturate the photo to such an extent that identification would be quite easy.

In view of the fact that carbonate cannot be identified by the bands detected by TM and, moreover, certain bands are easily mistaken for hydroxyls, it was decided that the PC and the comparison method should be used, using the limestone outcrops in the region of Polpaico as reference pattern. The limestone deposits of the open quarry could not be used as reference because their white colour and the outstanding reflection properties of the surface saturated all bands. The photos obtained by combining different PCs and bands were therefore modified so that their colours stressed the zones in which there were known to be limestone outcrops, whereas the rest of the photo was darkened, assuming that areas containing unknown limestone outcrops would be stressed to the same extent.

On three pictures in which known places were discernible with high definition, zones with the same colour were identified. These stressed regions were observed in at least two of the pictures. Finally, those places within the geological unit were selected which very probably contain limestone deposits.

3.2   Results of the photos

Below various places are presented which were selected from the photos and corresponded to the following combinations: Fig. 1: PC1/PC2/B1, Fig. 2: PC1/PC2/PC3, Fig. 3: PC2/PC3/PC4. They are shown to a scale of 1 :1 000 000 on the enclosed geological map.

From the comparison of the results of the various photos, the areas marked in Fig. 4 were selected. Already known limestone deposits are also marked on it. There is a clear relationship between their position and the selected regions for which reason it was assumed that a method suitable for the subsequent field work had been employed.
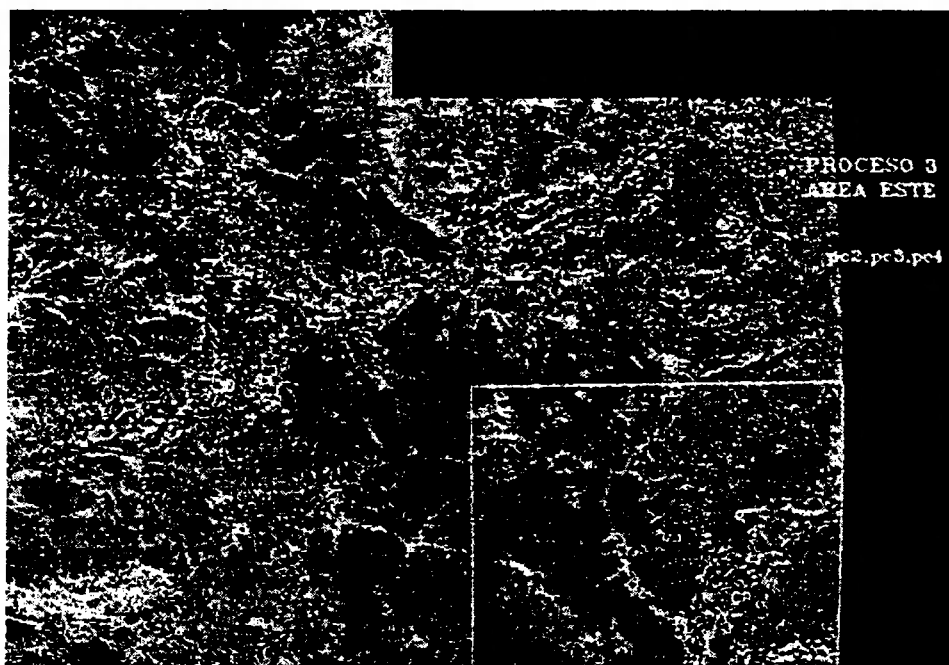
Fig. 1:   **PC1/PC2/B1: Points with a clear yellow colour and/or very weak red pigmentation were selected.**
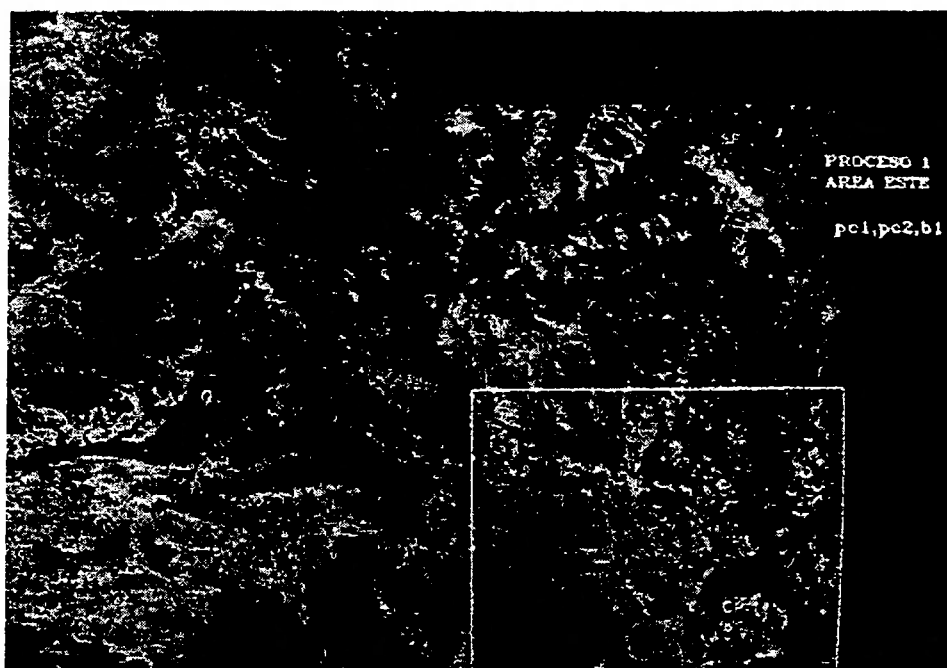
Fig. 2:   PC1/PC2/PC3: Points with a pink colour and light green pigmentation
             were selected.
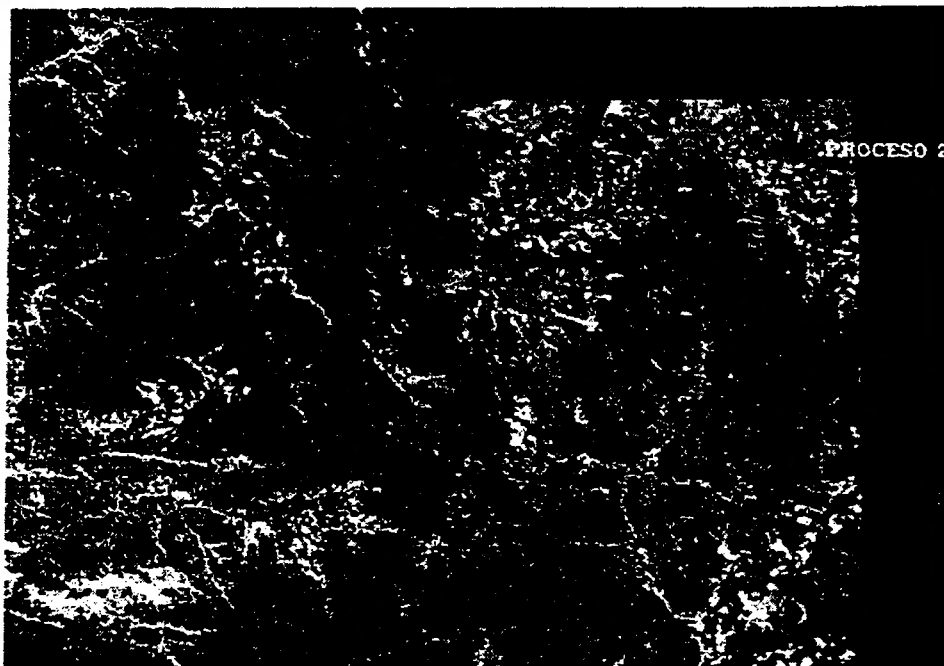
Fig. 3:   PC2/PC3/PC4: Points with a definite olive-green colour and a clear light-
             blue tinge were selected.

3.3   Results of examinations on site

Having determined the interesting areas, the zones were subsequently examined on the
spot where there were no known deposits. These were located in the geological units Jld,
Jdm J2 and west of the middle of Ki2 and KT (this work was carried out on a geological map
to a scale of 1 :250 000, which explains why much of the analysed geological information is
not reproduced) Limestone deposits were found.

Of the limestone deposits found only two proved favourable (> 80% CaCO3). Again, only one of these exhibited a volume of 1 million tonnes. It was located to the East of Puchuncavi, which had already been surveyed 2 months previously.

Judging from the limestone deposits found the project could not be declared as successful; this by no means applies to the geological aspect. Indeed, the new method proved to be extremely effective, because despite the difficult conditions of the terrain (above all due to the vegetation) a high correlation index was obtained (in 20 of the selected 32 areas there were known or newly found deposits).

The results proved that no further deposits can be expected in the area, which in turn forces the company to develop new geological strategies.

In the selected areas where finally no limestone was found, large areas of Andesite were found the colour of which closely resembles that of limestone or rocks with a weathered surface rich in carbonate. Other methods were also employed for exploring areas in which, according to literature, there are limestone deposits but which, on account of the dense vegetation (100%), could not be recognized on the photos (above all west of Polpaico).

Fig. 4   **On account of the comparison of the results of the various photos the areas shown were selected**
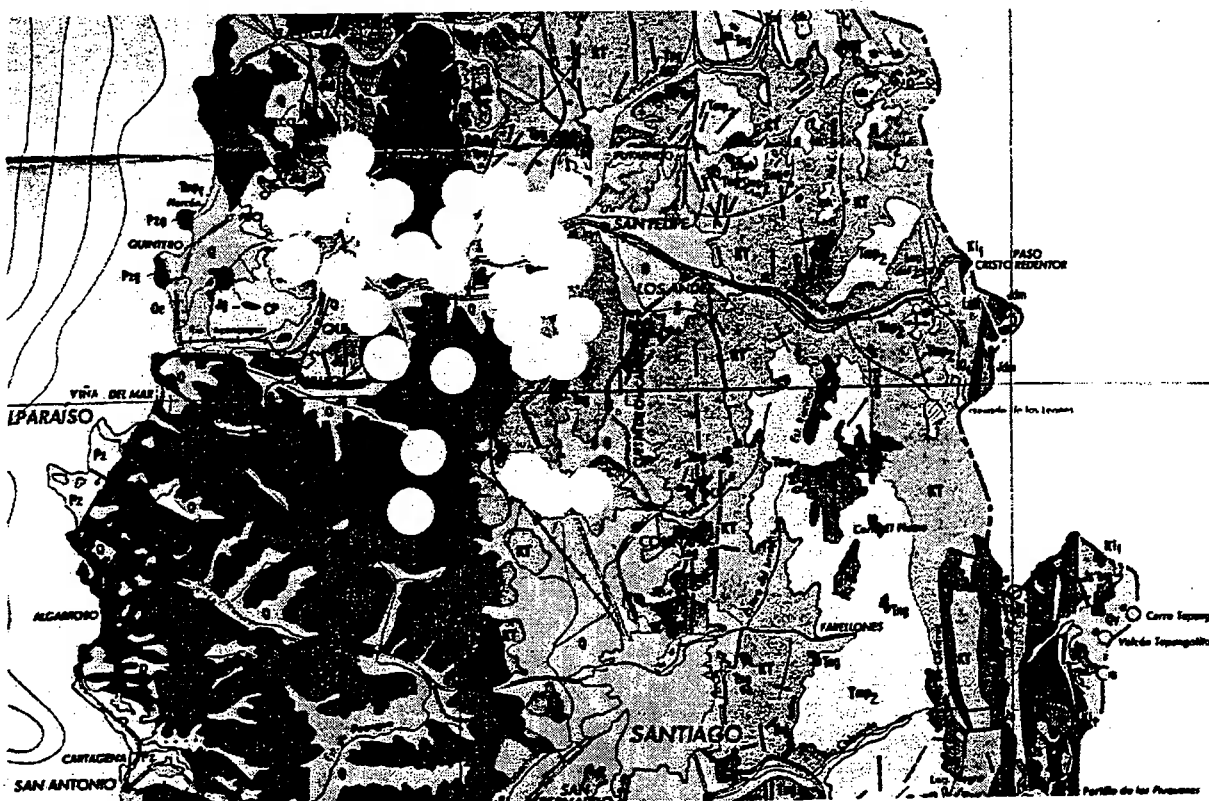
4.   CONCLUDING REMARKS

This method can be used in the regional search for limestone deposits. The subsequent local search does not last long and involves lower costs than when conventional methods are used (about 0.5 US$/m2), although the initial investment appears high.

Exclusive use of this method cannot solve the problem. It is essential to carefully study the literature at the same time, in order that adequate results may be obtained.

As regards the investigation carried out, it is judged to be a success from the geological point of view. In addition to the results (no limestone reserves in the area examined) it showed Polpaico the necessity for developing new strategies to locate additional reserves of raw materials in other areas.

We should like to thank Cemento Polpaico for financing and supporting us in the development of this new method, and the experts of the University of Chile for their active cooperation in analysing the information.